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CHARACTERISTICS OF SYSTEMS ENGINEERING IN AVIATION SCIENCE RESEARCH

by

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CHARACTERISTICS OF SYSTEMS ENGINEERING IN AVIATION SCIENCE RESEARCH /2

by Li Da-Li and Wu Jie-Zhi

There are five phases in aviation science research: fundamental research (to develop scientific theories), applied research (to generate technical projects), preliminary development (to test and verify technology, leading to product design), model development (to produce prototypes) and improvement after usage (or to develop practical models).

Preliminary research and development include fundamental research, applied research and preliminary development. In general, the main objective of the first two phases is to understand the subject, i.e., to explore the aviation science. The objective of the other three phases is to improve the status, that is to develop the aviation technology.

Considering aviation science research as a whole, it has many static characteristics such as divisibility, interrelatedness, stepwise progression, integrity, subordinateness, uncertainty, etc. However, the dynamic characteristics are more important which we would like to discuss in detail. That is the systems engineering of the aviation science research.

In practice, the systems engineering of aviation science research has the following meaningful characteristics:

BEGINNING WITH DIRECTING FUNDAMENTAL RESEARCH WITH SCIENTIFIC MANAGEMENT

Similar to other scientific studies, aviation science begins with fundamental research. It is the basis for independent and self-creative development of the aviation technology. Fundamental research in aviation science is a kind of systems engineering. It is an applied science or technology which contributes directly to the economics and the defense industries of the nation. It is different from the fundamental research of pure sciences such as mathematics, physics, chemistry, astronomy, geology, and biology, etc.

In the past, liberal basic research was regarded as the major form of fundamental research, and systems engineering was believed inapplicable to fundamental reserach. However, in recent extensive research activities, the situation of considering applications after completing liberal basic research has been replaced with directional research. In directional research the goals or objectives are well defined with organized research. For example the Apollo Program was defined to accomplish the goal of landing a manned spaceship on the Moon, which induced a major development in the technologies of propulsion and communication. In order to bring the second generation supersonic air cargo planes into reality, several new engine cycles as well as the related basic research on noise reduction and environment protection have been studied. For improving the surviving ability of fighter planes, related basic theories and the technology of "invisibility" have been developed. The research on the aerodynamic flow mechanism has been stimulated by the objective of obtaining advanced aerodynamic distribution. There are many similar examples available.

In the basic research we have also seen the approach where the goals are well defined. The construction of the world's largest high energy particle accelerator was for the purpose of discovering new basic particles and proving some important hypotheses of certain theories. Many fundamental studies on molecular biology and quantum biology are for the purpose of conquering cancer. Obviously, it is possible to include the directional fundamental research in systems engineering research. In order to effectively utilize the limited natural resources and to avoid repetition, omissions, and waste, it is necessary to put all directional fundamental research under one management. Therefore, for perfecting the systems engineering of aviation research, directional basic research should be carried out with scientific management, which is the starting point of the overall research and development project.

EMPHASIZING TECHNOLOGICAL VERIFICATION

The five stages of aviation science research have clearly indicated that the final goal is to generate products. This is different from certain basic research whose objective is to obtain scientific results. In aviation research additional attention should be paid to the phase of technology testing and verifying or the phase of preliminary development, since it serves as a link between past and future. It is the last stage of the preliminary research and the first stage of /3
development of aviation engineering. It is the linkage which transforms the achievement of scientific technology into practical production. It is a transition between understanding and improving the state of the art. Although we have seen that many new scientific concepts are mostly initiated in Europe, they are always first applied to new products in the United States. In addition to a strong economic and technological background, new technologies are verified in the research and development in the United States. It is named as "technological innovation" and is a national policy. Americans believe that the reason for having better technology in the United States than in the USSR is the "capability of utilizing useful science to develop various needed new equipment, which is better than the current applied technology, can be produced in large quantity, and is marketable to military and general consumers". In the United States, X-series experimental planes and the advanced testing planes have been used in the development of new planes. Engine cores or testing planes are manufactured for developing new engines. This phase, on the average, costs about one fifth of the total research and development budget. This approach has gradually been adopted by European countries.

CONTINUITY OF THE TECHNOLOGY FLOW

At the early stage of aviation systems engineering, basic and applied research was carried out using scientific approaches. The results led to many technology flows which progressed continuously and provided technological supports or information for the later phase of the research activity - the development phase or the phase for model development. These research activities should not stop at the model design. The technology flow should have the continuity as shown in Figure 1. This can provide sufficient technological supports which are necessary for model development. On the contrary, if a simple approach, "model leads the subject", is adopted, in which all the basic and the applied research is directed for the development of a specific current model due to limitations of the organization and the budget, the technology flow will cease at a particular model. There will be no consecutive development and no new information available for the development of later models, which will greatly extend the period of development.

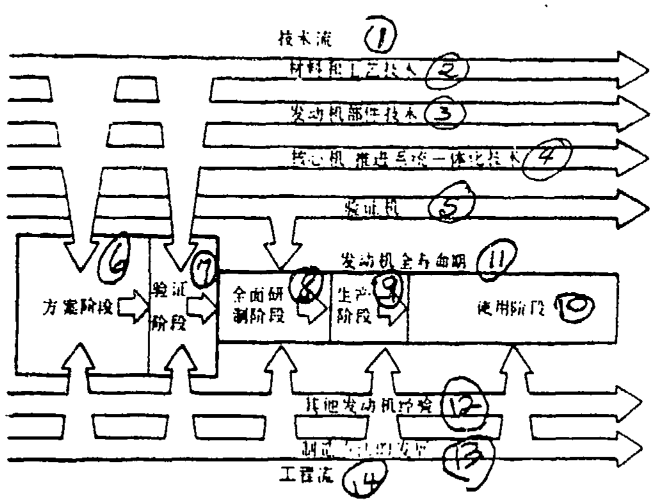

Figure 1. The relationship between preliminary research and the process of engine development.

1. Technology flow
2. Materials and industrial technology
3. Technology of engine parts
4. Engine core/propulsion system technology
5. Testing plane

6. Project phase
7. Testing and verifying phase
8. Full development phase
9. Production phase
10. Application phase
11. Life time of the engine
12. Other experience on engine
13. Manufacture Process development
14. Engineering flow

Obviously, we should not extend the technology flow without concerning the requirements of the model development. For a developing country, it usually can accomplish only one or two models with concentrated efforts within a short period. It is impossible to keep a broad technology flow independently without considering the model development. It is necessary to have a selected and defined domain and scale for the technology flow based on scientific forecasting of future models. One of the most important objectives of aviation systems engineering is to have a branched model development in various stages. The technically verified subjects should be timely applied to the development of every new model. The development of aerodynamic computation in the United States is a good example. For numerical simulation and modeling of the flow field using computers, it is necessary to develop and to debug a programming system employing a suitable advanced computer. For more accurate modeling, which needs more calculations, a more advanced and sophisticated computer is required. For this reason, NASA has carried out four preliminary to advanced stages of the project on the development of the computation aerodynamics. While using the computer for practical design and calculation in the first phase, the calculation program for the second phase is also developed. When the new computer is developed in the second phase, the new program is employed for carrying out more accurate calculations and a new program to be used in the third phase is developed simultaneously. The progress of each phase is shown in Figure 2. In this approach, the program development forms a continuous technological flow. A practical new program or information flow is always available for the design department as soon as a new computer is developed. Various phases are "synchronized" with the development of the computer.

/4

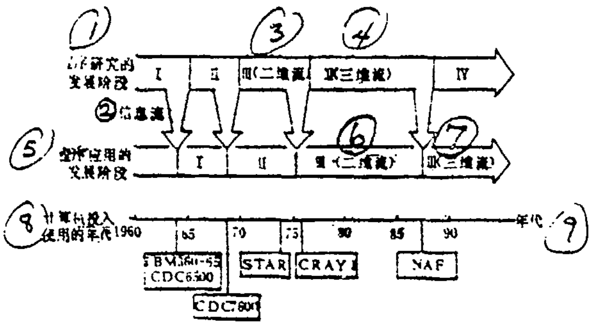

Figure 2. The stepwise development of computer and computation aerodynamics in the United States.

1. The development phase of program research
2. Information flow
3. Two dimensional flow
4. Three dimensional flow
5. The development phase of program application
6. Two dimensional flow
7. Three dimensional flow
8. The starting year of the new computer in application
9. Year

This well planned and progressive approach is one of the main reasons for rapid development of the computation aerodynamics in the United States.

FLEXIBILITY AND CREATIVITY

Creativity is one of the important characteristics in any scientific research systems, especially for a large one. It provides a series of important issues for the systems engineering innovation, creating active academic environments, paying attention to the flexibility of the plan, and enhancing the international academic exchange or information research, etc. It is different from managing of an engineering or a business system. The scientists who joined the Manhatten Project (from which systems engineering science was born) to build the first batch of atomic bombs recalled the days when they first arrived at the project center at Los Alamos. The scientists felt that they were gathering for free discussion like mathematicians in a university campus but not for a crash project on the development of secret weapons. It is to our benefit to ponder over the tale-like description.

In the systems engineering of scientific research, starting with directional basic research, a flexible management is necessary to encourage the creativity and innovation, and to avoid the suppression of the development of some new and unrecognized technology.

The U.S. Department of Defense has adopted a policy which allows the contractors to use 1 to 3% of the contract budget in carrying out free basic research for encouraging new ideas. This policy can derive substantial benefits with minimum expense.

To establish the spirit of creativity, it is necessary to carry out creative reformation by doing painstaking work. It is also necessary to promote brave thinking, innovation as well as contention of a hundred schools of thought in schools, research organizations and various leading authorities. It is very important to gradually improve education and the system for developing talented persons as well as to advance the quality of the professionals.

USING EXCESS MARGIN APPROACH TO OVERCOME PROBLEMS IN TECHNOLOGY

Recognizing risk and encouraging innovation, as mentioned previously, are the initial steps for solving problems in the systems engineering of the scientific research. In practical research, we cannot always be sure that a specific field of research will be accomplished as predicted even though we are determined to solve it and have used systems analysis to recognize the weak points of the project. There are too many unknown factors in scientific research. Many problems cannot be changed by subjective desire or wishful thinking. Therefore, it should take a policy of excess margin approach to the key technologies which have definite influence on the overall system. Certainly this will cost more and it is named "investment on risk". Although it is more costly in some areas, it may be a big saving for the whole system, based on the "life time expense". Time is money, and is even more important than money in certain occasions, especially for developing timely weapon systems or competitive products which may determine the fate of the company.

The policy of using excess efforts had been used in the Manhatten Project in the United States. The crux in the development of the atomic bomb was to produce the splittable material. Only a few more months were necessary for producing the atomic bombs if the splittable material was available. Therefore, four different processes had been in progress simultaneously in the United States to produce the splittable material. Nobody felt that the approach was wasteful for the following reasons. First, the successful development of atomic bombs timely fulfilled the requirement of the warfare. Second, although three of the processes had not been employed directly in the production of the atomic bomb, they had been applied to other technologies which increased the technology reserve and improved the economy.

The approach of using excess efforts to resolve problems in technology and the basic strategic thinking of shortening the battle front with concentrated force complemented each other. In the overall arrangement of a scientific and technological research system, all the manpower, financial resources and materials have to be concentrated on the main subjects or models according to the principles of "taking ourselves as the dominant factor" and "generalizing the system". However,

when the general problems have been solved and finally the roughest spots are revealed, we have to organize and utilize the second, third and fourth shift of forces and fight /5
determinedly for the last battle similar to the general offensive and the final fight for capturing the enemy's fortress.

THE "ENTROPY" OF THE SYSTEMS ENGINEERING IN SCIENTIFIC AND TECHNOLOGICAL RESEARCH AND THE HUMAN FACTOR

An aircraft is a vital man-made system. Aviation research is also a vital and even more complicated man-made system. It has tens of thousands of scientists, workers and leaders of various levels. Obviously, we should pay great attention to the human factor when we discuss the characteristics of the systems engineering of aviation research and development.

The human factor is normally revealed as the guiding principle. policy, or system of organization and management. It is the main consideration in the aviation research system. The efficiency of the systems engineering of scientific research depends on its policy, guiding principle, organization and management as well as on human relations. Foreign countries have been using the physical concept of "entropy" to represent the extent of randomness and the orderless condition or the extent of "internal consumption". In other words, a good systems engineering design of aviation research should have the lowest "entropy". Everybody's effort should be converted to useful work with maximum efficiency for achieving greater, faster, better and more economical scientific results as well as obtaining maximum benefit for the economy. Although zero entropy, such as the movement of celestial bodies which precisely follow the laws of mechanics, does not exist in society's daily life, making great efforts to lower the internal consumption of the scientific and technological research system is possible and necessary.

Foreign nations have paid great attention to the adaptability of the management and organization to systems engineering of scientific research. They believe that a good management can promote the progress of research work and activate the research environment, while bad management will destroy research and make it worthless. In addition, we should also pay great attention to the capability of accurately employing qualified personnel and exploiting intelligence and potentials to a great extent, this affects the efficiency of converting the system's "internal energy" to useful work.

Systems engineering is a branch of science. It should have the necessary stability and authority and should not be changed or interferred with arbitrarily after the plans and projects are established according to the techniques of the systems engineering. This is the key point which determines the possibility of effectively applying systems engineering to aviation research. Empiricism, selfish departmentalism, mismanagement, official's intention and so forth are opposi-tive to the scientific method in systems engineering, which greatly increase the internal consumption and reduce the ef-ficiency. No better mathematical model can be applied if the above mentioned problems cannot be overcome. A developing country cannot afford to waste time and money caused by the presence of the above problems. It will be very painful if the meticulously constructed setup of the research systems engineering is destroyed in a moment by certain man-made in-terference, and if the scientific research budget, which has been obtained with innumerable hardships, is wasted by the increase of "entropy" instead of in science. Therefore, how to establish a system of aviation research systems engineering is a very sharp and urgent question.

With more observation and analyses on the systems engi-neering of aviation research, we will feel more deeply the complexity of the system as well as the interconnection, mutual permeation, mutual dependence and mutual containing of the branched systems, subsystems and sub-subsystems.

However, who should be responsible for organizing these interconnected and mutual permeative areas and phases of the research activities? Who should be responsible for organizing the large amount of preliminary research activities and for coordinating and settling the activities which extend across the research system and the systems engineering? Apparently, it is similar to an army consisting of many different arms, which needs a strong general staff. It is necessary to establish a system headquarters for taking the whole responsibility in the main aviation research system and in the first level subsystems. The headquarters should have the foresight and be capable of predicting the future. The headquarters should be in the highest for commanding the whole system. It should be an advisory organization which can provide advices for the leader of the aviation research system in making decisions. Therefore, it should have the data bases for the purpose of comparison and verifying calculations and have the capability of establishing mathematical models and carrying out calculations for testing and verification. On the other hand, the headquarters should be a commanding organization. It should provide directions, lay down programs, perform inspections and conduct allocations. Swedish Saab-37 has taken the policy of the closely coupled duck pattern arrangement, which was suggested by an authoritative brain trust. Even a small country can take such an advanced arrangement which has not been tried previously by anyone. It clearly indicates the importance of a system headquarters with foresight and sagacity.

It appears that the question of the necessity of establishing a low "entropy" headquarters for the aviation research and development system has been deeply considered and seriously discussed by more and more people.

(1)各国合金结构钢标准、牌号、性能对照表（棒材、锻件）

(2)中国	(3)苏联	(4)美国	(5)英国	(6)法国	(7)日本	(8)联邦德国	C	(9)主要化学元素含量% Si	Mn	Cr	Ni	Mo	(12)机械性能（不小于） σ_b kgf/mm²	δ %	ψ %	a_k kg-m/cm²	(13)用途
YB674-73 12CrNi3A	ГОСТ4543-71 12XH3A	— —	BS970-3-71 ~655M13*	— —	JISG4102-79 ~SNC815	— —	0.10~0.16			0.60~0.90	2.75~3.25		90	12	55	12	[illegible] (14)
YB674-73 12Cr2Ni4A	ГОСТ4543-71 12X2H4A	ASTMA335-79 E3310.3310	BS970-3-71 ~659M15*	— —	— —	— —	0.10~0.16			1.25~1.75	3.25~3.75		105	12	55	10	[illegible] (15)
YB674-73 18Cr2Ni4WA	ГОСТ4543-71 18X2H4BA*	— —	BS970-3-71 ~835M15*	— —	— —	— —	0.13~0.19			1.35~1.65	4.00~4.50	0.25~0.35 或W0.80~1.20	115（油淬空冷） 105（空冷） (16)	11 12	45 50	10 12	[illegible] (16)
YB674-73 38CrA	ГОСТ4543-71 38XA	ASTMA29-81 ~5140	BS970-2-70 ~530M40*	NFA35-552-82 38Cr4	JISG4104-79 SCr440*	— —	0.34~0.42			0.80~1.10			(17) 90	12	50	10	[illegible] (17)
YB674-73 30CrMnSiA	ГОСТ4543-71 30XГCA	— —	— —	— —	— —	— —	0.28~0.35	0.90~1.20	0.80~1.10	0.80~1.10			110	10	45	5	(18) [illegible]
YB674-73 30CrMnSiNi2A	ГОСТ4543-71 30XГCH2A*	— —	— —	— —	— —	— —	0.27~0.34	0.90~1.20	1.00~1.30	0.90~1.20	1.40~1.80		160	9	45	6	飞机起落架、接头、螺栓 (19)
YB674-73 38CrMoAlA	ГОСТ4543-71 38X2MЮA*	ASTMA355-81 氮化钢 (10)	BS970-2-70 905M39*	NFA35-552-82 40CAD6-12	JISG4202-79 ~SACM645*	DIN17211-70 ~41CrAlMo7	0.35~0.42			1.35~1.65	0.15~0.25 Al 0.70~1.10	0.15~0.25	98	15	50	10	(20) [illegible]
YB674-73 40CrNiMoA	ГОСТ4543-71 40XH2MA*	ASTMA29-81 E4340.4340	BS970-2-70 817M40*	— —	JISG4103-79 SNCM439*	DIN17200-69 ~36NiCrMo4	0.36~0.44			0.60~0.90	1.25~1.75	0.15~0.25	100	12	45	9	(21) [illegible]
YB6-59 60Si2MnA	ГОСТ2052-53 60C2A	ASTMA59-81 9260	BS970-5-71 250A61	— —	JISG4801-77 SUP7	DIN17221-72 60SiMn7	0.56~0.64	1.50~2.00	0.60~0.90				160	5	20	—	[illegible] (22)
YB6-59 65Si2MnWA	ГОСТ2052-53 60C2BA	— —	— —	— —	— —	— —	0.61~0.69	1.50~2.00	0.70~1.00				190	5	20	—	[illegible] (23)
YB674-73 50CrVA	ГОСТ2052-53 50XФA	ASTMA29-81 6150	BS970-5-72 735A50*	NFA35-552-82 50CV4	JIS4801-77 SUP10	DIN17200-69 50CrV4	0.46~0.54			0.80~1.10		V 0.10~0.20	130	10	45	—	[illegible] (24)
YB9-68 GCr15	ГОСТ801-78 ШX15	ASTMA295-79 E52100 52100	BS970-2-70 535A99*	NFA35-565-82 100C6	JIS4805-70 SUJ2	DIN17230-80 100Cr6	0.95~1.05			1.30~1.65			—	—	—	—	[illegible] (25)

(11)注：1. [illegible] 2. [illegible] 3. [illegible] 4. [illegible]

(28)[illegible]

1. Cross Reference of the specification, code and property of various structural alloy steels (rods, forgings)
2. China
3. USSR
4. USA
5. England
6. France
7. Japan
8. West Germany
9. Main chemical elements content, %
10. Nitriding Steel
11. Note: 1. *New code; 2. All chemical constitutions and properties listed in the table are chinese standards; 3. The specifications listed are all current new standards; 4. ~Similar steel code.
12. Mechanical properties (not less than)
13. Applications
14. Carbonized parts such as gear, shaft, piston ring, oil pump rotor, etc.
15. Carbonized parts such as gear, shaft, piston ring, oil pump rotor, etc.
16. Turbine shaft, compressor shaft, blade, gear
17. Bolts, nuts
18. Welded and riveted construction, antiabrasive parts
19. Landing gear, connectors, bolts
20. Parts which need nitriding
21. Parts for various shafts, bolts for shaft neck, connectors
22. Plate springs, coil springs
23. Most important coil springs
24. Important springs, pull rods
25. Bearing parts, valve jackets, turbine engine nozzle
26. Low temperature annealed
27. Treated
28. Organized by Liu Zhong-Qiu